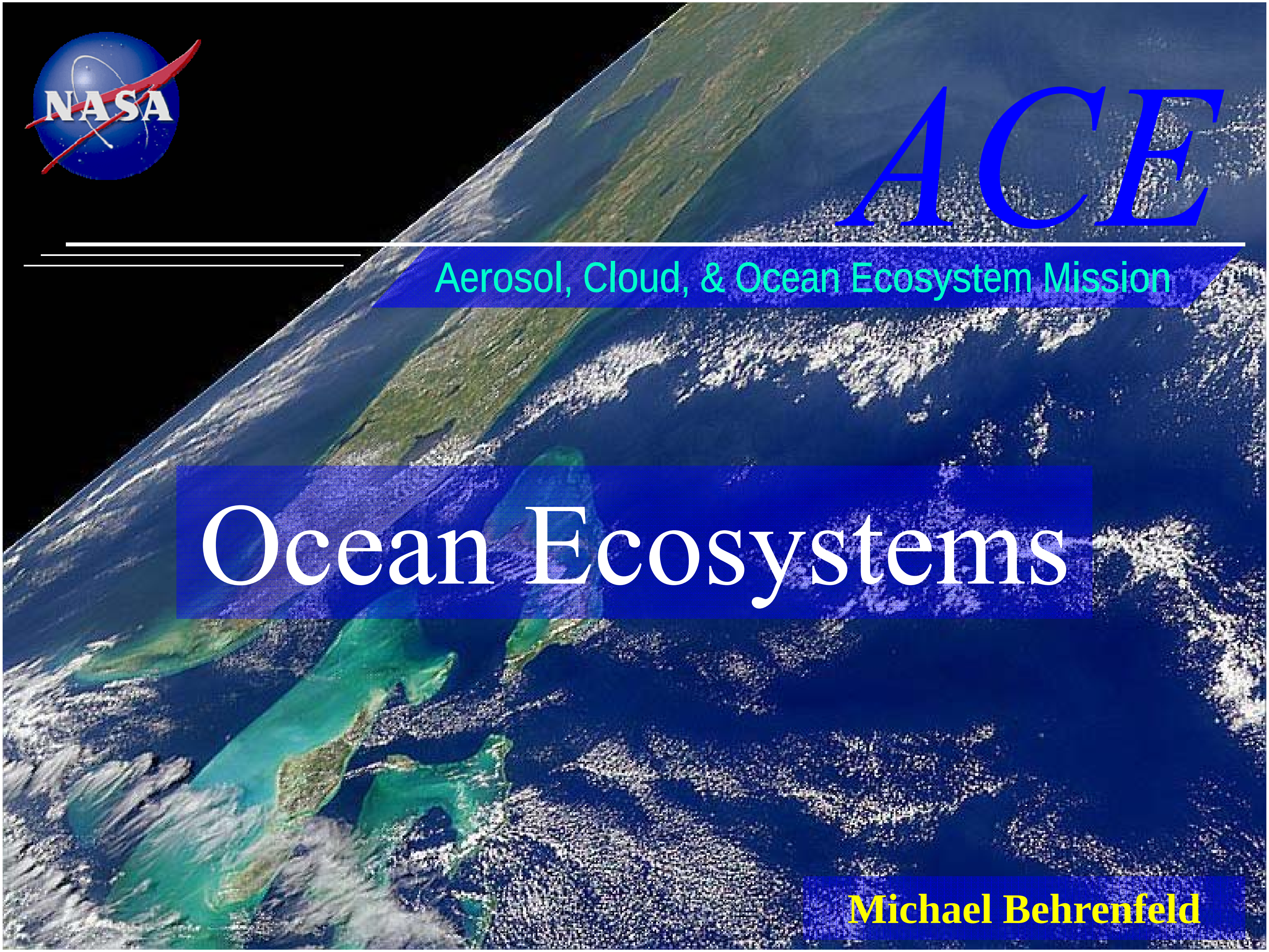
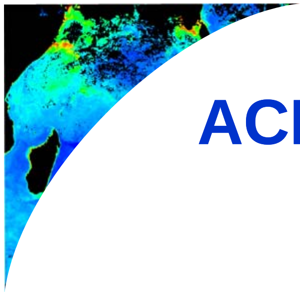


ACE

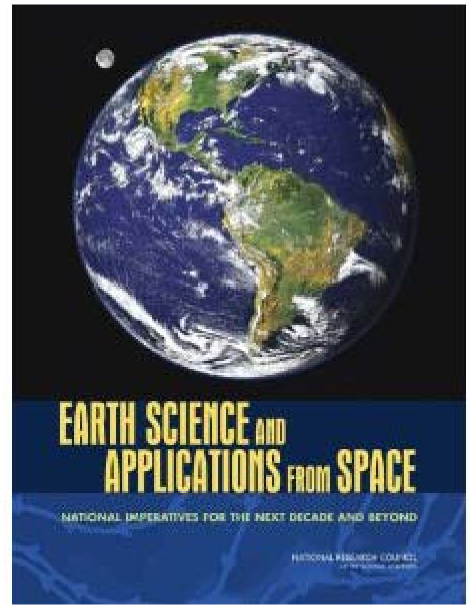
Aerosol, Cloud, & Ocean Ecosystem Mission

Ocean Ecosystems

Michael Behrenfeld



ACE Ocean Ecosystem Science



ACE ecosystem measurements target:

1. Phytoplankton CO_2 uptake (i.e., photosynthesis)
2. Carbon flow through ecosystems
3. Harmful algal blooms
4. Climate forcings on ocean ecosystems
5. Impacts of aeolian fertilization
6. Ecosystem structure influencing carbon uptake
7. Organic carbon stocks
8. Reduce uncertainties in model predictions

ACE instrument suite will contribute to:

1. Atmospheric correction for ecosystem products
2. Aerosol-Ecosystem interactions
3. Characterization of ecosystem stocks

Climate Change and Ocean Ecosystems

DS Objective: Evaluate effect of climate change on ocean ecosystems

Current Status: Heritage satellite observations show clear link between 'ocean color' (interpreted as chlorophyll stocks) and changes in temperature and stratification at regional to global scale

Issues:

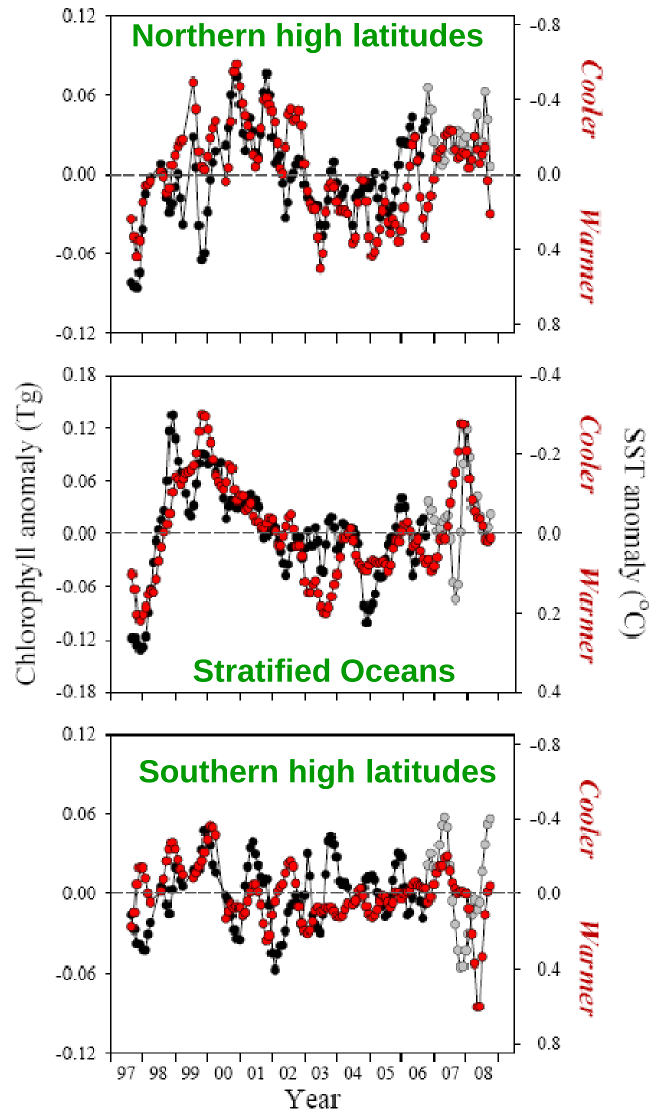
(1) What are the mechanisms of such relationships?

- Phytoplankton or dissolved organics?
- Biomass or physiology?

(2) Why do high latitudes differ from expectations?

(3) What are the ecological implications?

- Positively or negatively correlated with productivity?
- Shifts in species composition or functional groups?



Climate Change and Ocean Ecosystems

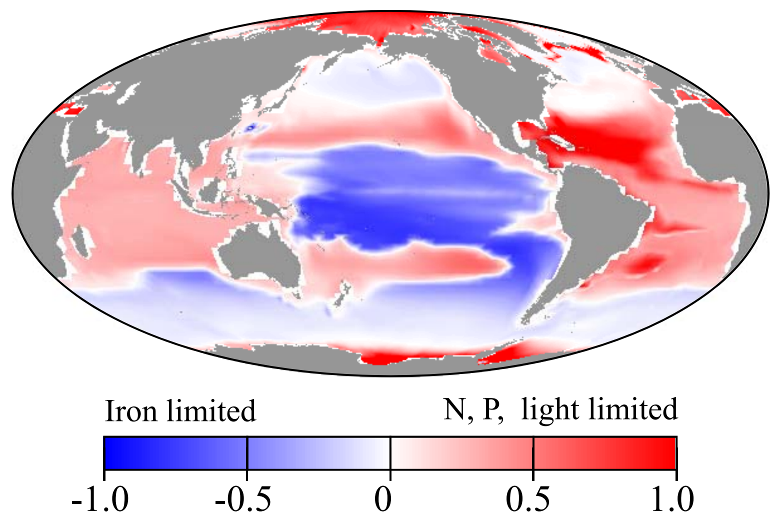
DS Objective: Reduce uncertainties in predicted climate change effects on ocean ecosystems and carbon budget

Current Status: Ocean Circulation Ecosystem Models provide a tool for evaluating climate change impacts on ocean productivity, carbon stocks, and major phytoplankton groups

Issues:

(1) Many modeled ecosystem properties are not currently derived with heritage satellite observational bands

(2) Uncertainties in current satellite products compromise model evaluations



Model-based prediction of factors limiting phytoplankton growth

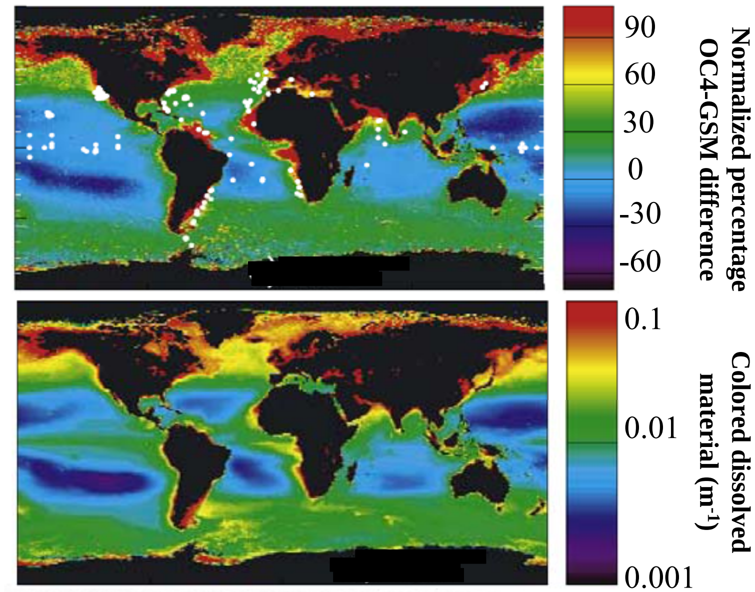
Specific Paths for Scientific Advances

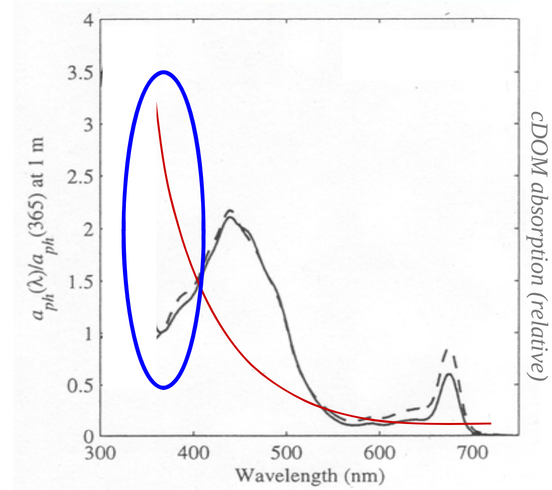
Paths for Scientific Advances

DS Objective: Accurate separation of pigments and colored dissolved organic matter (cDOM)

Current Status: Uncertainty in pigment-cDOM retrievals introduce ocean productivity uncertain of order 10 Pg C y^{-1}

Approach: Measurements in *near-UV* will enable more accurate separation of absorbing compounds





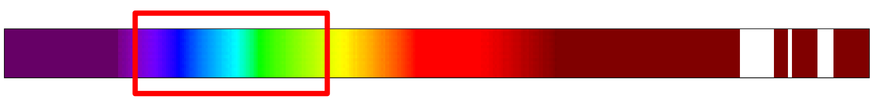
Siegel et al., GEOPHYSICAL RESEARCH LETTERS, VOL. 32, L20605, doi:10.1029/2005GL024310, 2005

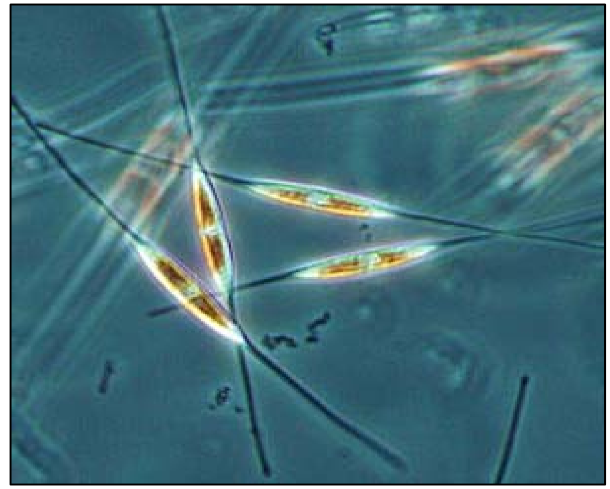
Paths for Scientific Advances

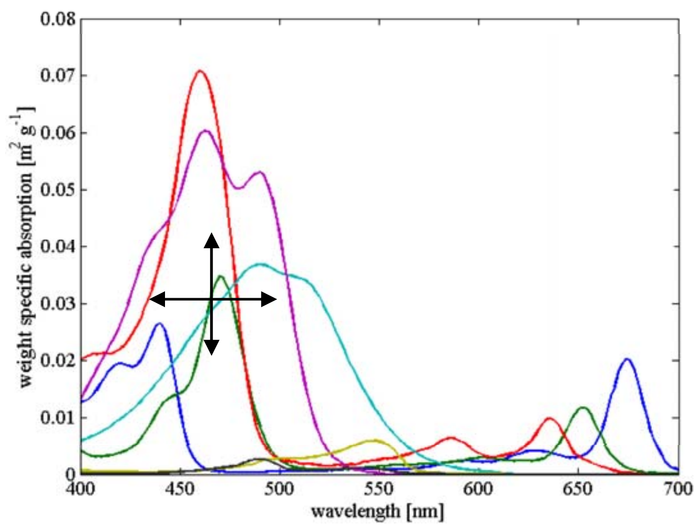
DS Objective: Assess ocean phytoplankton productivity and change

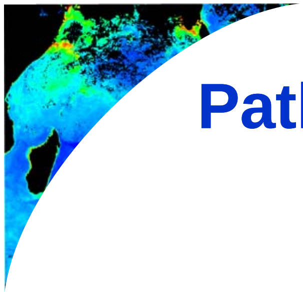
Current Status: Productivity is a function of light absorption by phytoplankton, not simply chlorophyll concentration. Heritage satellite bands limit evaluation of spectral absorption

Approach: Increase spectral *resolution in the blue-green region* to characterize pigment absorption amplitude and breadth







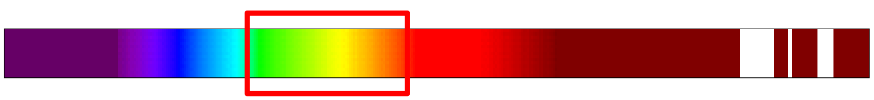


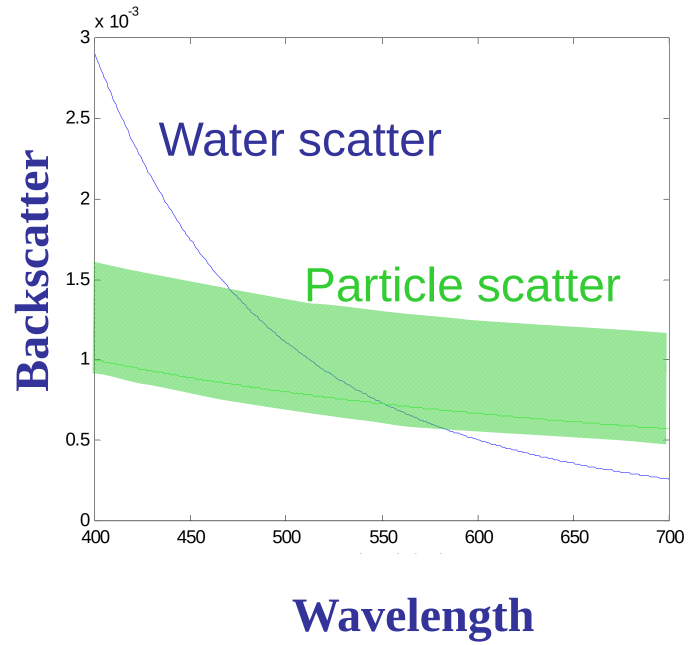
Paths for Scientific Advances

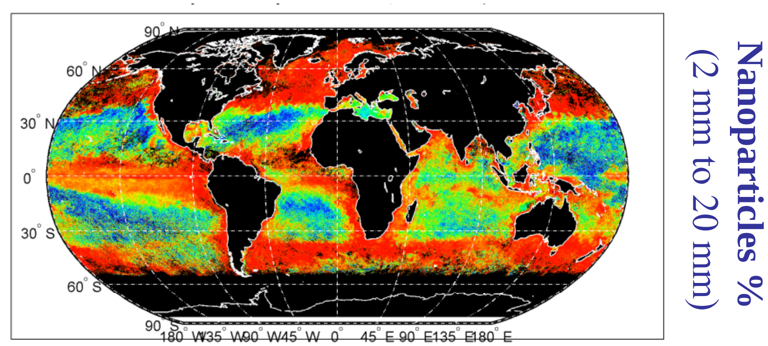
DS Objective: Quantify ocean ecosystem change and carbon stocks

Current Status: Changes in ecosystem structure impact particle size distributions, which in turn influence optical backscattering properties and their relation to particulate organic carbon (POC). Heritage bands limit evaluation of spectral shape of backscattering

Approach: Increase measurement *resolution in the green-yellow region* (‘flat area of pigment absorption spectra) to characterize spectral backscattering slope and POC





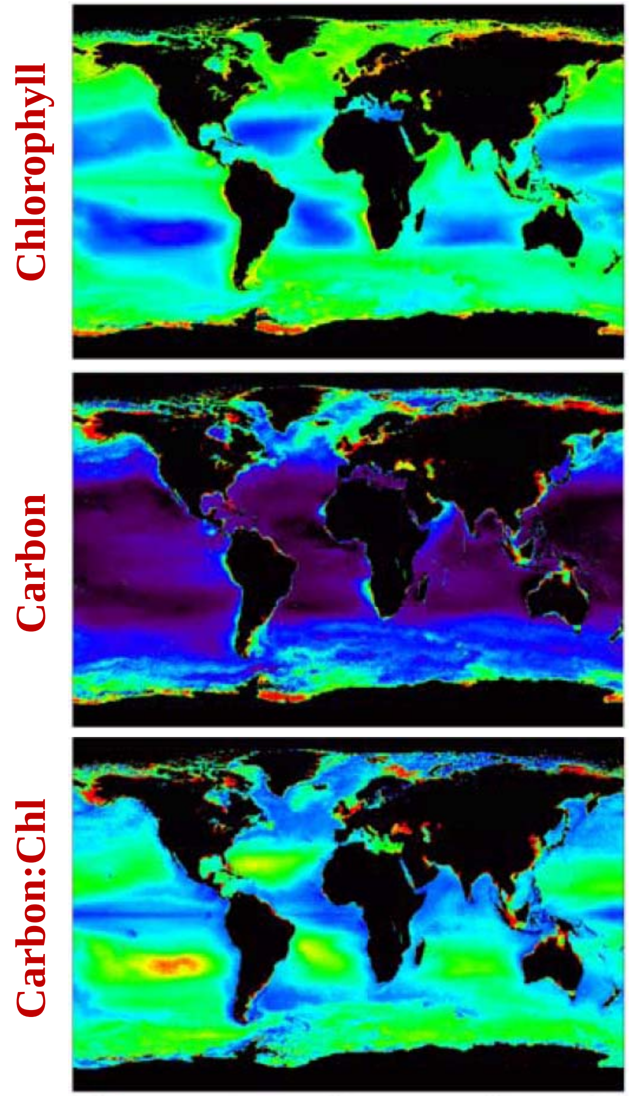


Paths for Scientific Advances

DS Objective: Estimate carbon uptake through ocean ecosystems

Current Status: Photosynthesis is the first step in ecosystem carbon uptake and is a product of both phytoplankton carbon stock and physiological state (i.e., ‘health).

Approach: Improved spectral resolution in the *UV and visible region* allows retrieval of phytoplankton carbon (from backscattering) and physiology (from ratio of carbon-to-pigment absorption)



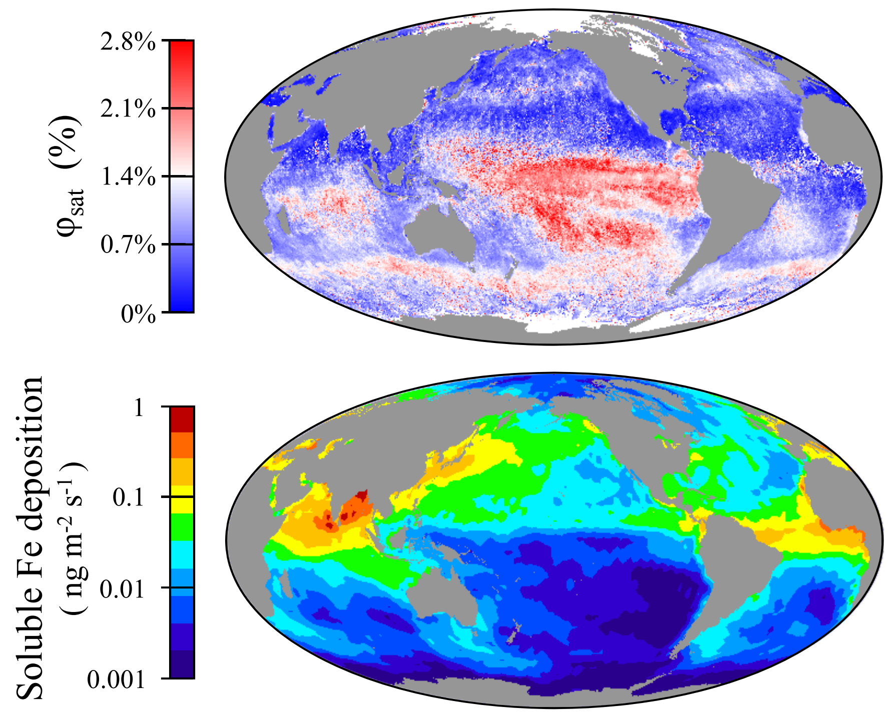
SIEGEL ET AL JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 110, C07011, doi:10.1029/2004JC002527, 2005

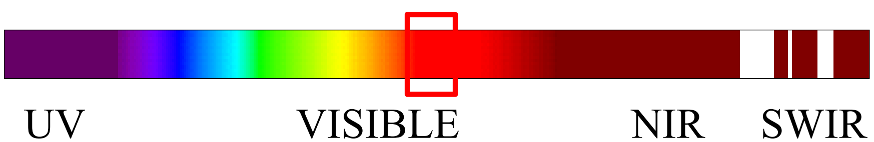
Paths for Scientific Advances

DS Objective: Evaluate aeolian fertilization on marine ecosystems

Current Status: MODIS Aqua data reveal high phytoplankton fluorescence yields under low iron conditions, allowing study of aeolian fertilization effects. However, currently planned US ocean sensors lack fluorescence bands

Approach: Include chlorophyll fluorescence detection bands



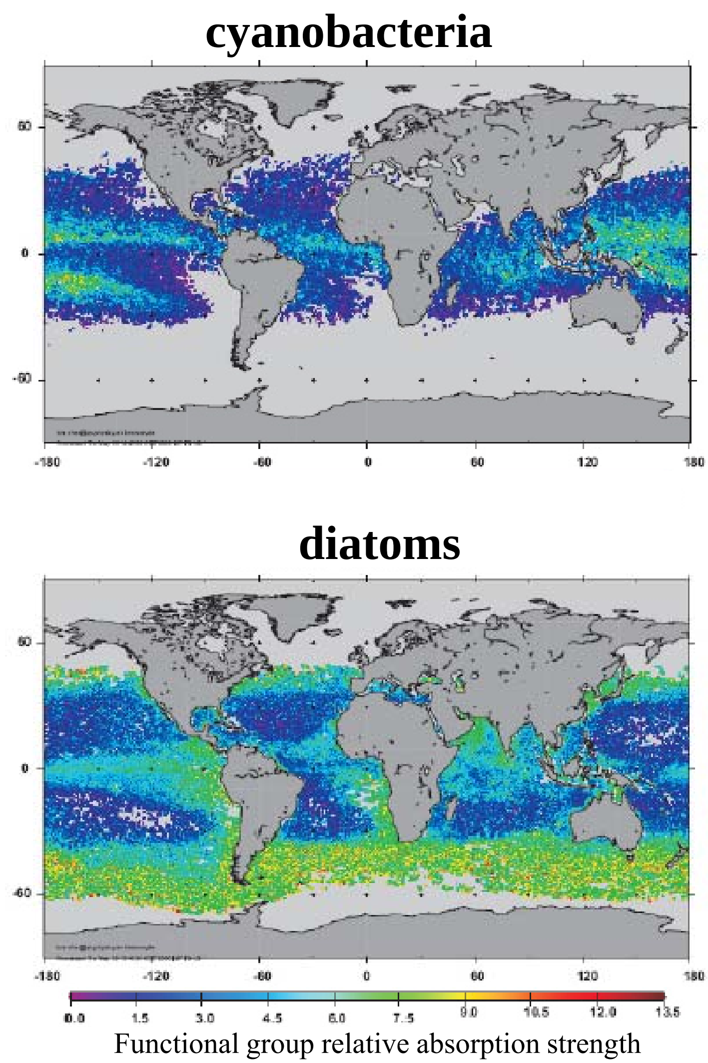


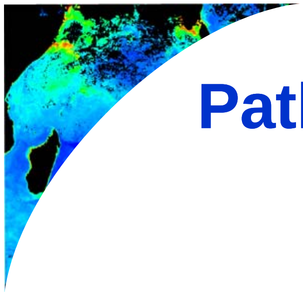
Paths for Scientific Advances

DS Objective: Assess effects of climate forcings on ocean ecosystems and harmful algal blooms

Current Status: Key phytoplankton groups have unique absorption features that can be detected through derivative analyses of high spectral resolution remote sensing data (as demonstrated using SCIAMACHY). Algorithms have also been developed for single specific groups (N-fixers, calcifiers)

Approach: Measure and downlink UV through visible data at 5 nm resolution



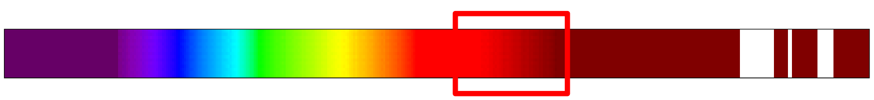


Paths for Scientific Advances

DS Objective: Quantify ecosystem carbon and productivity

Current Status: Key properties in optically complex coastal and inland waters can be retrieved from measurements near the 'red edge' of pigment absorption

Approach: Extend high resolution measurements from the visible into the near infrared



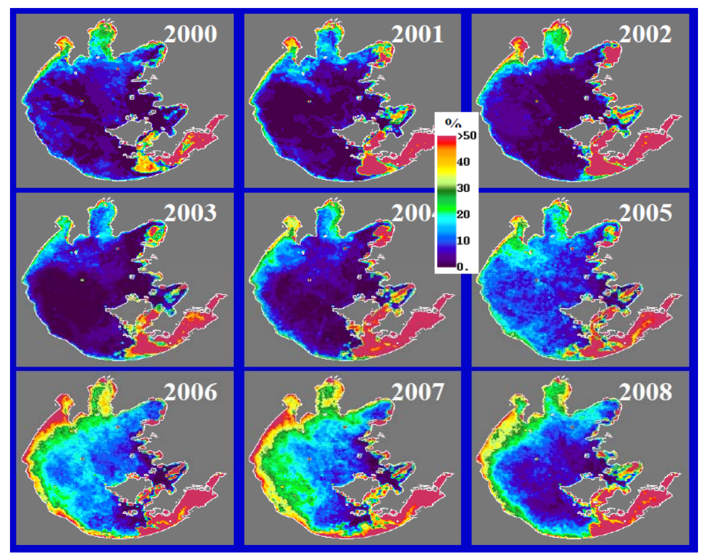


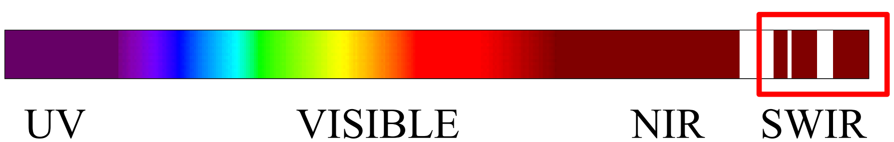
Image & data from Chuanmin Hu, Univ. South Florida

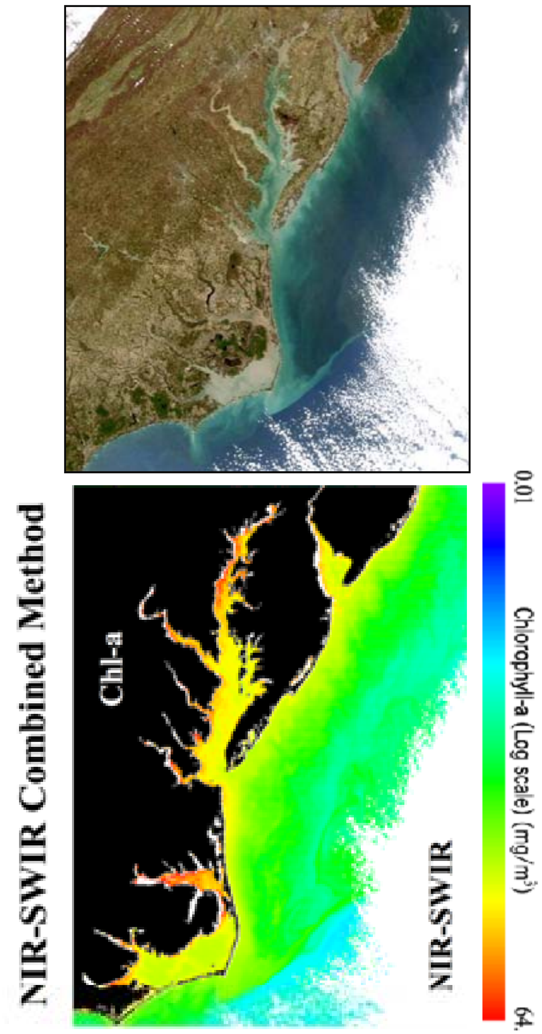
Paths for Scientific Advances

DS Objective: Quantify ocean ecosystem carbon and productivity

Current Status: In highly-productive but turbid ocean areas, atmospheric corrections must be based on measurements at wavelengths longer than the NIR

Approach: Include discrete measurements bands in the short-wave infrared (SWIR)





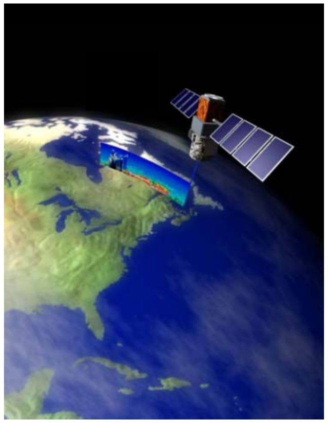
From: Wang, M. and W. Shi (2007) *Optics Express*, **15**, 15722-15733.

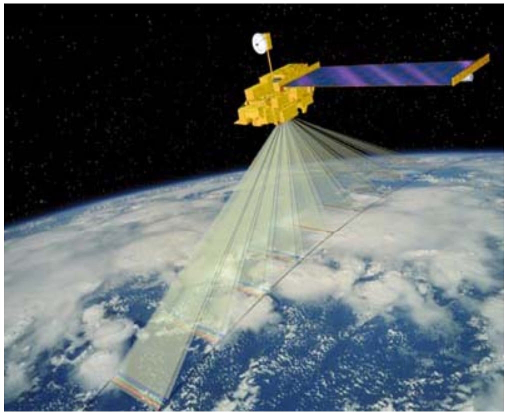
Multi-instrument, Cross-disciplinary Science with ACE

Benefits for ACE instrument suite

Improved Atmospheric Corrections (*>90% of TOA signal*)

- Passive radiometer: UV (350 nm) spectral ‘anchoring’; NIR & SWIR
- Polarimeter: Aerosol Characterization
- LIDAR: Aerosol Heights



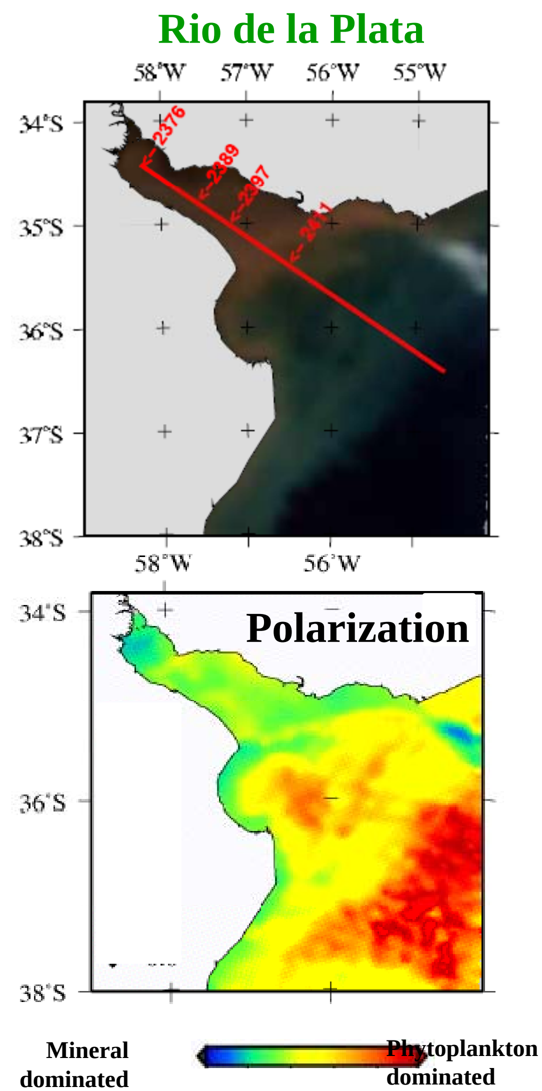


Benefits for ACE instrument suite

- ❑ *Carbon dynamics* are influenced by biotic and mineral particles, which have different polarization properties

- ❑ Combining passive ocean radiometer data with **polarimeter measurements** allows characterization of particle assemblages, as recently demonstrated with POLDER data

- ❑ Improves understanding *land-ocean materials exchange and carbon flow*



Loisel et al., 18 August 2008 / Vol. 16, No. 17 / OPTICS EXPRESS

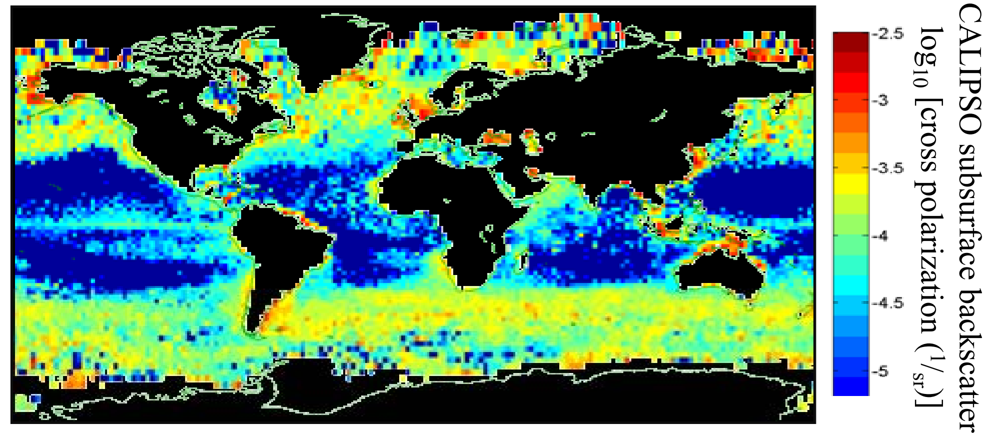
Benefits for ACE instrument suite

- ❑ Ocean subsurface LIDAR returns demonstrated using CALIOP measurements, although improved vertical resolution needed

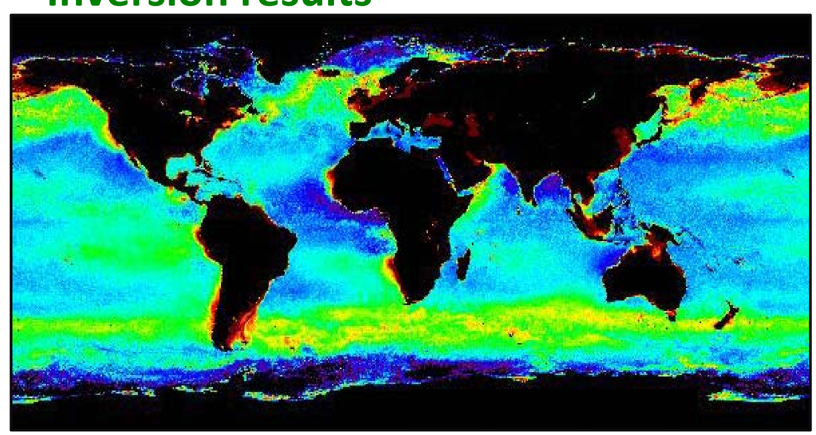
- ❑ Provides independent measure of *backscatter* and *particle profiling*.

- ❑ LIDAR surface measurements may also significantly improve *air-sea* CO_2 *exchange estimates*

Lidar results



Inversion results



Data from Yong Hu, NASA Langley

Ocean Ecosystem
Science Traceability
Matrix (STM)

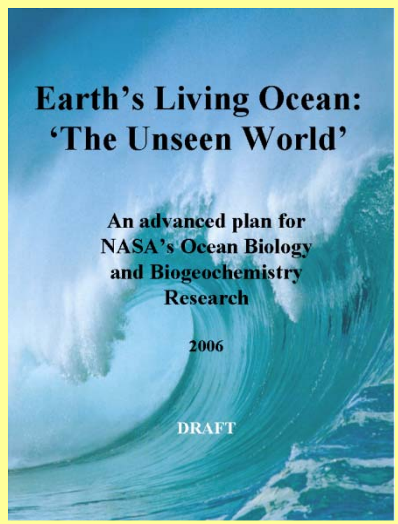
Ocean Ecosystems STM

Goddard Space Flight Center

Category	Focused Questions*	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs
Ocean Biology	1 What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing? [OBB1] 2 How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? [OBB2] 3 What are the material exchanges between land & ocean? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing? [OBB1,2,3] 4 How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system? [OBB2] 5 How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics? [OBB1,2] 6 What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing? [OBB1,4]	Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), and productivity usi... models & chlor... Measure partic... carbon pools, th... and optical prop... Quantify ocean... &... Es... di... As... ... flu... Co... gr... bi... ex... physical proper... SST, SSH, etc)... dynamics, horiz... Combine ACE observations wi... (1) air-sea exch... dissolved mater... (2) impacts on ... properties Assess ocean ra... feedbacks Conduct field s... measurements and modeling to validate retrievals from the pelagic to near-shore environments	1 2 ... ... 2 5 3 6	Water-leaving radiances in near-ultraviolet, visible, & ...	• 5 nm resolution 350 to 755 nm ▷ 1000 – 1500 SNR for 15 nm aggregate bands UV & visible ...d 10 nm fluorescence bands ...5, 678, 710, 748 nm centers) ... to 40 nm width atmospheric ...rection bands at 748, 765, 820, ...5, 1245, 1640, 2135 nm ... radiometric temporal stability ...month demonstrated prelaunch) ... cross track scanning ...or tilt (±20°) for glint avoidance ...rization insensitive (<1.0%) ... spatial resolution @ nadir ...aturation in UV to NIR bands ...ar minimum design lifetime ...m aerosol vertical resolution ...ub-surface resolution ...% polarization misalignment ...01 km^{-1}sr^{-1} aerosol backscatter ...vity at 532 nm after averaging ...s e-folding transient response ...ouin scattering capability; ...er FOVs: 0-60 m; 0-120 m. ...rvation angles: 60° to 140° ...e resolution: 5° ...ee of polarization: 1% ...ory Measurements ... & round-robin algorithm testing ...ent & protocols development, ...) measurement comparisons ... ocean biomes (coast/open ocean) ...M, DOM, pCO2, PSDs, IOPs, ...es, bio-available Fe concentrations	Orbit permitting 2-day global coverage of ocean radiometer measurements Sun-synchronous orbit with crossing time between 10:30 a.m. & 1:30 p.m. Storage and download of full spectral and spatial data Monthly lunar calibration at 7° phase angle through Earth observing port	Global data sets from missions, models, or field observations: *Measurement Requirements* (1) Ozone (2) Total water vapor (3) Surface wind velocity (4) Surface barometric pressure (5) NO_2 concentration (6) Vicarious calibration & validation** (7) Full prelaunch characterization (2% accuracy radiometric) *Science Requirements* (1) SST (2) SSH (3) PAR (4) UV (5) MLD (6) CO_2 (7) pH (8) Ocean circulation (9) Aerosol deposition (10) run-off loading in coastal zone
				...osystem Modeling • Expand model capabilities to assimilate variables such as NPP, IOPs, and phytoplankton species/functional group concentrations. • Improve model process parameterizations, e.g., particle fluxes			

Si... O... Qu...

Each question maps to the OBBP plan



* ACE focused questions are traceable to the four overarching science questions of NASA's Ocean Biology and Biogeochemistry Program [OBB1 to OBB4] as defined in the document: *Earth's Living Ocean: A Strategic Vision for the NASA Ocean Biological and Biogeochemistry Program* (under NRC review)

** See ACE Ocean Ecosystem white paper for specific vicarious calibration & validation requirements

Ocean Ecosystems STM

Goddard Space Flight Center

Category	Focused Questions*
Ocean Biology	**1** What are the standing stocks, composition, & productivity of ocean ecosystems? How and why are they changing? [OBB1]
	2 How and why are ocean biogeochemical cycles changing? How do they influence the Earth system? [OBB2]
	3 What are the material exchanges between land & ocean? How do they influence coastal ecosystems, biogeochemistry & habitats? How are they changing? [OBB1,2,3]
	4 How do aerosols & clouds influence ocean ecosystems & biogeochemical cycles? How do ocean biological & photochemical processes affect the atmosphere and Earth system? [OBB2]
	5 How do physical ocean processes affect ocean ecosystems & biogeochemistry? How do ocean biological processes influence ocean physics? [OBB1,2]
	6 What is the distribution of algal blooms and their relation to harmful algal and eutrophication events? How are these events changing? [OBB1,4]

Ecosystem stock changes

Changes in ocean biogeochemistry

Coastal systems & land-ocean exchange

Ocean-atmosphere interactions

Interaction of physics & ecosystems

Phytoplankton blooms & eutrophication

Characterize phytoplankton communities & rates

Particulate & dissolved carbon

Photochemistry

Particle abundance

Assimilation

Comparison with ground

Evaluate air-sea exchange & aerosol/cloud properties with obs.

Ocean radiant heating & feedback

Field measurements & models to validate retrievals

Numbers link Approaches to Science Questions

* ACE focused questions are traceable to the four overarching science questions of NASA ... the document: *Earth's Living Ocean: A Strategic Vision for the NASA Ocean Biological and Biogeochemistry Program* (under NRC review)

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Ocean Ecosystems STM

Goddard Space Flight Center

Category	Focused Questions*	Approach	Maps to Science Question	Measurement Requirements	Instrument Requirements	Platform Requir'ts	Other Needs
Ocean Biology	1 What are the standing stocks, composition, & productivity of ocean ecosyst… and why are they… [OBB1]	Quantify phytoplankton biomass, pigments, optical properties, key groups (functional/HABS), and …	1	Water-leaving radiances in near-ultraviolet, visible, & … …ration …ring …ulation …scence	**Radiometer** • 5 nm resolution 350 to 755 nm ▷ 1000 – 1500 SNR for 15 nm aggregate bands UV & visible and 10 nm fluorescence bands (665, 678, 710, 748 nm centers) ▷ 10 to 40 nm width atmospheric correction bands at 748, 765, 820, 865, 1245, 1640, 2135 nm … stability … prelaunch) … nt avoidance … <1.0%) … nadir … IR bands … ifetime	Orbit permitting 2-day global coverage of ocean radiometer measurements Sun-synchronous orbit with crossing time between 10:30 a.m. & 1:30 p.m. Storage and download of full spectral and spatial data Monthly lunar calibration at 7… phase angle through Earth observing port	Global data sets from missions, models, or field observations: *Measurement Requirements* (1) Ozone (2) Total water vapor (3) Surface wind velocity (4) Surface barometric pressure (5) NO_2 concentration (6) Vicarious calibration & validation** (7) Full prelaunch characterization (2% accuracy radiometric) *Science Requirements* (1) SST (2) SSH (3) PAR (4) UV (5) MLD (6) CO_2 (7) pH (8) Ocean circulation (9) Aerosol deposition (10) run-off loading in coastal zone
	2 How and why ar… biogeochemical… changing? How… influence the Ear… [OBB2]						
	3 What are the mat… exchanges betwe… ocean? How do they influence coastal ecosystems, biogeochemistry… How are they ch… [OBB1,2,3]	Assimilate ACE observations …			**Lidar** …solution …n …ignment …ckscatter …averaging • < 4 ns e-folding transient response • Brillouin scattering capability; Receiver FOVs: 0-60 m; 0-120 m.		
	4 How do aerosols… influence ocean… & biogeochemical cycles? How do ocean biological & …	ground-based and model data of biological properties, land-ocean exchange in the coastal zone	3 4	… scattering & depth profile			
				… spatial coverage …l heights and single … albedo for … …pheric correctio… …rface polarized return for typing oceanic particles	**Polarimeter** • Observation angles: 60° to 140° • Angle resolution: 5° • Degree of polarization: 1%		
	5 H… processes affect ocean ecosystems & …	observations with models to evaluate (1) … …ates, …and	4	**Supporting Field & Laboratory Measurements** • Primary production (NPP) measurement & round-robin algorithm testing • Inherent optical properties (IOPs) instrument & protocols development, laboratory & field (coastal and open ocean) measurement comparisons • Measure key phytoplankton groups across ocean biomes (coast/open ocean) • Expanded global data sets of NPP, CDOM, DOM, pCO2, PSDs, IOPs, fluorescence, vertical organic particle fluxes, bio-available Fe concentrations			
	6 What is the distribution of …	…nd feedbacks	5				
		…agic	1 4 … 3 6	**Ocean Biogeochemistry-Ecosystem Modeling** • Expand model capabilities to assimilate variables such as NPP, IOPs, and phytoplankton species/functional group concentrations. • Improve model process parameterizations, e.g., particle fluxes			

Ocean Ecosystem Spectrometer
- UV/Vis high spectral resolution
- Fluorescence cap…
- NIR & SWIR ba…
- Sensor tilt

2-day global coverage
near-noon orbit
full data downlink
monthly lunar viewing

Lidar: aerosol prof…
subsurface scatteri… @ 2 m res.

Requirements for *Polarimeter* defined by Aerosol Team

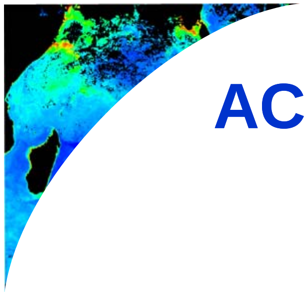
Expanding field component critical to new ACE products

Value of ACE data for models &
Value of models for ACE science

* ACE focused questions are traceable to the four overarching science questions of NASA's Ocean Biology and Biogeochemistry Program [OBB1 to OBB4] as defined in the document: *Earth's Living Ocean: A Strategic Vision for the NASA Ocean Biological and Biogeochemistry Program* (under NRC review)

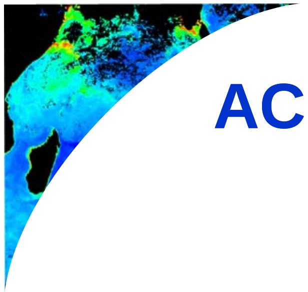
** See ACE Ocean Ecosystem white paper for specific vicarious calibration & validation requirements

ACE Ocean Ecosystem Field and Development Activities & Requirements



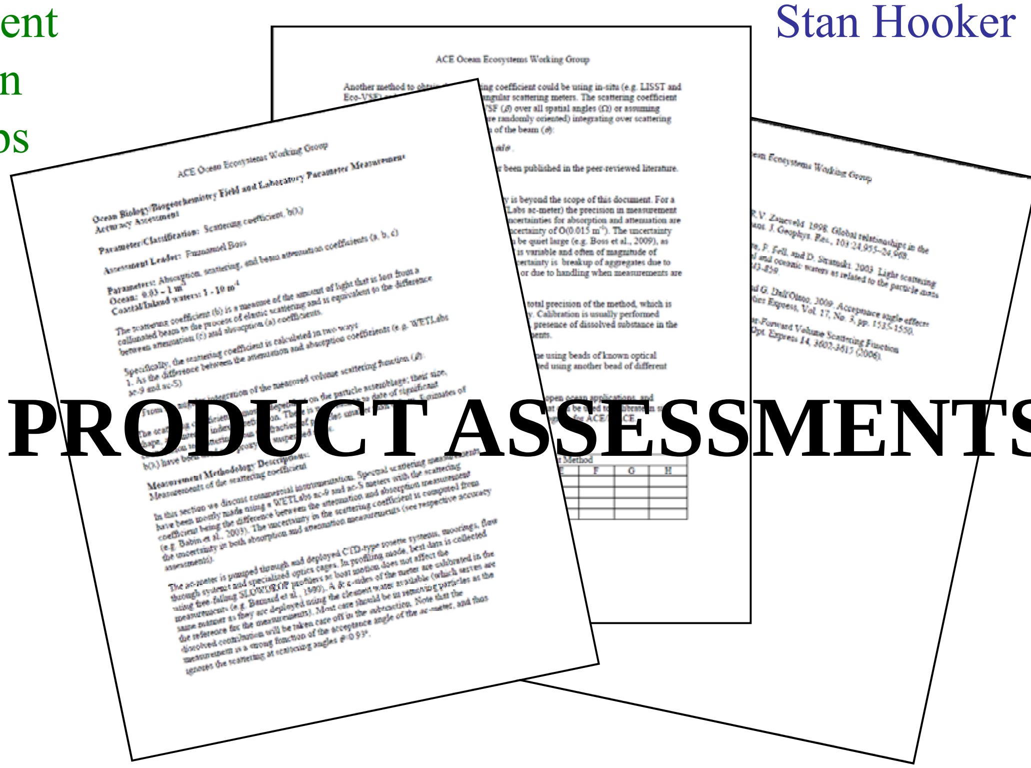
ACE Ocean Parameters & Climate Data Records

Heritage CDRs	*Field Accuracy Assessment Lead*
• Normalized water-leaving radiances	Stan Hooker
• Chlorophyll-a	Stan Hooker
• Diffuse attenuation coefficient (490 nm)	Stan Hooker
ACE Candidate CDRs	
• Inherent optical properties	Norm Nelson
• Spectral Kd	Stan Hooker
• Spectral RSR	Stan Hooker
• Particulate organic carbon concentration	Darius Stramski
• Primary production	Mike Behrenfeld
• Calcite concentration	Barney Balch
• Colored dissolved organic matter	Norm Nelson, Antonio Mannino
• Photosynthetically available radiation	Robert Frouin
• Fluorescence line height	Mike Behrenfeld
• Euphotic depth	Zhongping Lee
• Total suspended matter	Rick Stumpf
• Trichodesmium concentration	Toby Westberry



ACE Ocean Parameters & Climate Data Records

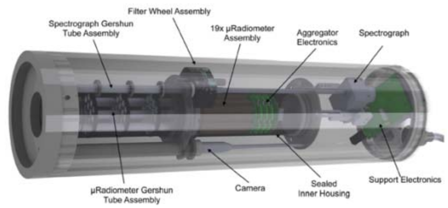
Research products	***Field Accuracy Assessment Lead***
Particle size distributions & composition	Dave Siegel
Phytoplankton carbon	Mike Behrenfeld, Joe Salisbury
Dissolved organic matter/carbon	Antonio Mannino, Joe Salisbury
Physiological properties	Mike Behrenfeld
Other plant pigment	Stan Hooker
Export production	
Taxonomic groups	



PRODUCT ASSESSMENTS

ACE Ocean Parameters & Climate Data Records

- Ocean radiometer vicarious calibration technology development
  - Extended wavelength range and spectral resolution compared to heritage instruments
  - Campaign formulation for suborbital and field measurements – plan formulation needed



OSPREy

- Data collection for novel products algorithm development
  - Extended wavelength range for in-water optics
  - Novel products require development of measurement techniques/protocols for validation: *particle size spectra, phytoplankton functional types, phytoplankton carbon, solar-stimulated chlorophyll fluorescence, physiological diagnostics*

- Algorithm development
  - Expanded product suite from spectral inversion algorithms
  - Merging sensor data (radiometer, polarimeter, LIDAR) for atmospheric corrections
  - Expanding derivative analysis products
  - Development opportunities with existing data sets


ACE
Aerosol, Cloud, & Ocean Ecosystem Mission
Thank You

ACE Ocean Ecology Working Group

Chuck McClain: Chair
Paula Bontempi: Co-chair

- Zia Ahmad (NASA/GSFC)
- Bob Barnes (NASA/GSFC)
- Mike Behrenfeld (Oregon State U.)
- Emmanuel Boss (U. of Maine)
- Steve Brown (NIST)
- Jacek Chowdhary (NASA/GISS)
- Robert Frouin (U. California/San Diego)
- Howard Gordon (U. of Miami)
- Stan Hooker (NASA/GSFC)
- Yong Hu (NASA LaRC)
- Stephane Maritorena (UC/Santa Barbara)
- Gerhard Meister (NASA/GSFC)
- Norm Nelson (UC/Santa Barbara)
- Dave Siegel (UC/Santa Barbara)
- Rick Stumpf (NOAA/NOS)
- Menghua Wang (NOAA/NESDIS)

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